MuCool Test Area Progress and Plans

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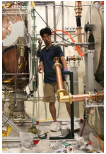
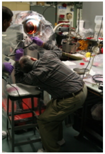
Illinois Institute of Technology/Fermilab

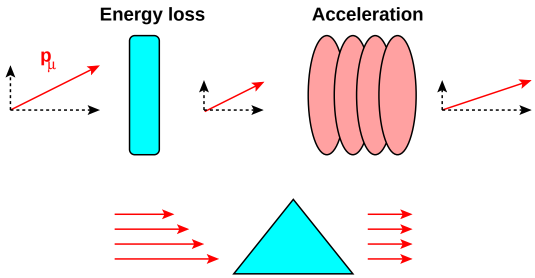
All Experimenters' Mtg
Aug 6, 2012 – Fermilab




Ionization Cooling

- The only muon cooling scheme that appears practical within the muon lifetime (2.2μs)



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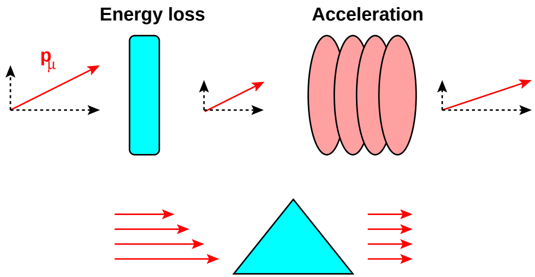

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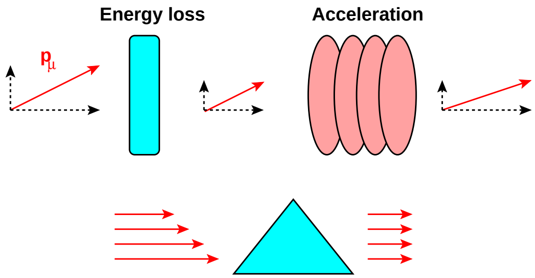

- Cooling mainly transverse in a linear channel
- Longitudinal cooling requires momentum-dependent path-length through the energy absorbers

Ionization Cooling

Normalized transverse emittance ε of muon beam in solenoidal channel

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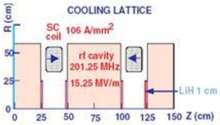

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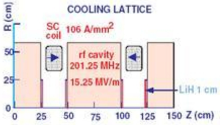

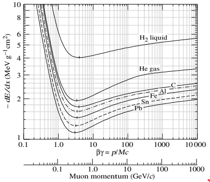

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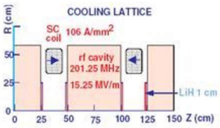
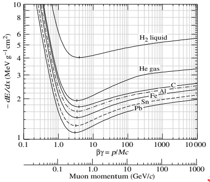
- emittance exchange for 6D cooling (or twisted field – Guggenheim, HCC, snake)





MuCool

R&D program at Fermilab to develop ionization cooling components

mission:

- design, prototype and test components for ionization cooling
  - absorbers (LH2, solid LiH)
  - RF cavities
  - magnets
  - diagnostics
- carry out associated simulation and theoretical studies
- support system tests (MICE, future cooling experiments)

Current focus: RF in high external magnetic field

Potential Solutions

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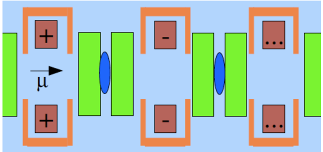
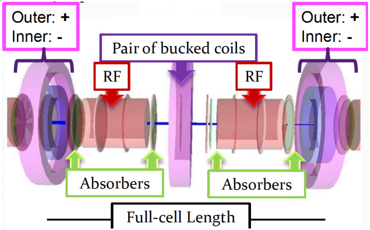
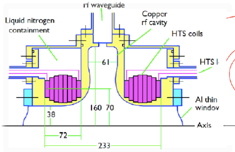
3. Shielding: iron, bucking coils

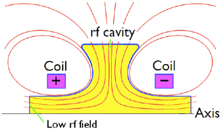




Potential Solutions

4. Magnetic insulation: modified cavity/coil designs to keep B⊥E on cavity surfaces (R. Palmer *et al.*)





Loss of x 2 gradient advantage in pillbox geometry
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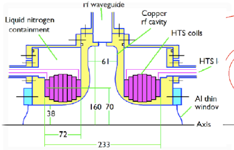

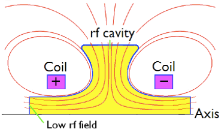

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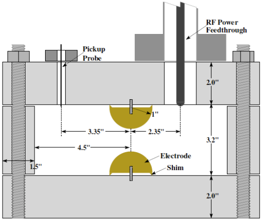
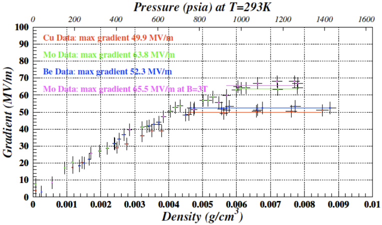
5. High-pressure gas: suppress breakdown by moderating electrons (R. Johnson *et al.*, Muons Inc.)

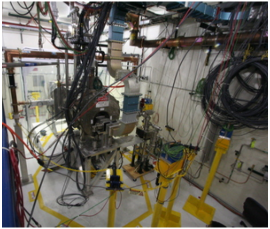




MuCool Test Area (MTA) – http://mice.iit.edu/mta/

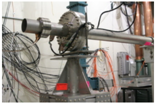
Dedicated facility at the end of the Linac built to address MuCool needs

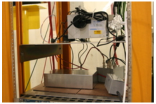
- RF power (12 MW at 805 MHz, 5 MW at 201 MHz)
- 5 T superconducting solenoid
- 805 and 201 MHz cavities
- Radiation detectors
- Cryogenic plant
- 400 MeV p beamline
- Class-100 portable clean room
- Hydrogen safety infrastructure

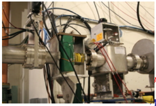


MTA Diagnostics

- RF forward, reflected, pickup signals
- Vacuum pressure
- Scintillator+PMT counters for X-ray rates, spectra
- Ionization chambers for radiation dose rates
- Spectrometer for cavity light analysis
- Thermocouples for cavity temperature
- Acoustic sensors for spark detection (under development)
- Toroids for beam intensity
- BPM, MW and scintillator for beam profile
- Environmental monitoring







Summary of MuCool experimental program

- trying to demonstrate a working solution to RF cavity operation in high external magnetic field for muon cooling
- major MAP milestone (and technical risk for MICE)
- big impact on cooling channel design and future system tests
- multipronged approach to cover maximum ground with available resources

Cavity	Outstanding issues	Proposed resolution	Experimental tests
Vacuum pillbox	Breakdown and damage	Better materials	Mo, W, Be buttons Be-walled 805-MHz cavity
		Surface processing	Electropolished buttons 201-MHz pillbox in B-field
		Coatings	ALD-coated buttons ALD-coated cavity
Vacuum rectangular open-iris		Magnetic insulation	$E\perp B$ box cavity $E\parallel B$ box cavity Modified cavity-coil geometry
Pressurized	B-field/pressure effects	Materials tests	805-MHz 4-season cavity
	Beam-induced ionization	Measure ionization lifetime	805-MHz cavity in beam
	Frequency dependence	Test at different frequency	Pressurized 201-MHz cavity

Students at the MTA (past 1.5 year)

- Lisa Nash (U. Chicago) – HPRF
- Adam Sibley (Trinity) – HPRF breakdown study
- Oleg Lysenko (U. Chicago) – HPRF beam test
- Jared Gaynier (Kettering) – circulator installation
- Jessica Cenni (Pisa) – dielectric loaded cavity
- Tom Mclaughlin (Valparaiso) – magnet mapping, circulator installation
- Ivan Orlov (Moscow State) – HPRF beam test simulation
- Raul Campos (NC State) – beamline magnet support
- Peter Lane (IIT) – acoustic sensors for spark detection
- Timofey Zolkin (U. Chicago) – dark current instrumentation
- Giulia Collura (Torino) – HPRF beam test
- Ben Freemire (IIT) – HPRF beam test (thesis), +lots more
- Last Feremenga (U. Chicago) – magnetic field mapping
- Anastasia Belozertseva (U. Chicago) – magnetic field mapping

805-MHz pillbox button cavity

- Pillbox geometry with thin curved Be windows
- Button holder for removable electrode inserts
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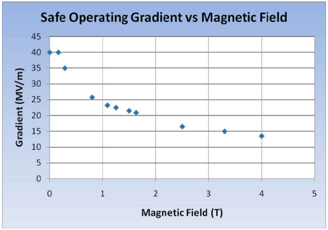

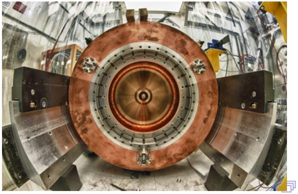

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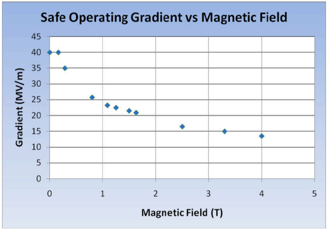

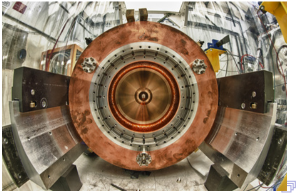

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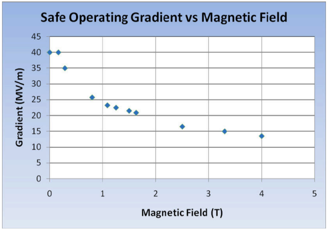

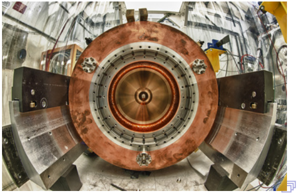

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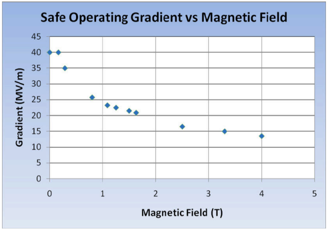

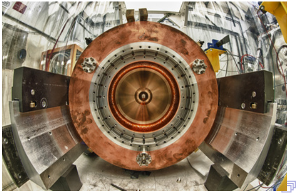

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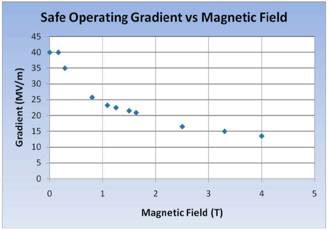

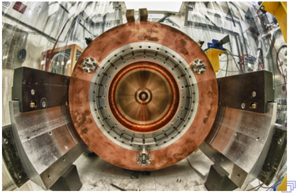

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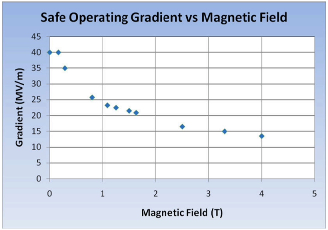

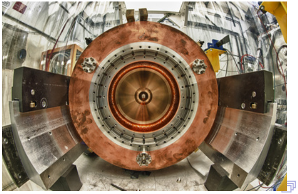

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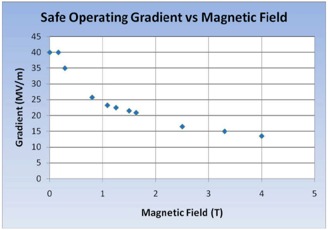
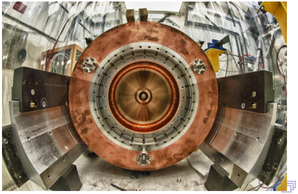
- Refurbished at JLab
- Ran with Be & Cu buttons (similar max gradient)

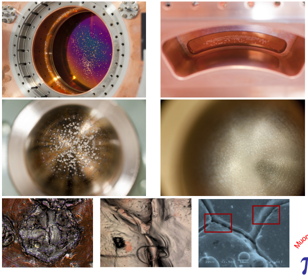




805-MHz pillbox button cavity

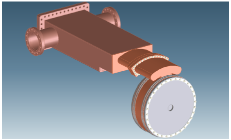
- Poor performance after refurbishing
- possibly from coupler area damage
- Tested Be and Cu buttons
- did somewhat better with Be than Cu
- conservative conditioning with Be due to safety concerns
- After flat-endplate runs
  - Additional damage to problem areas (iris, coupler)
  - Deposits on endplates
- After button runs
  - More damage on Cu buttons
  - Some features on Be buttons also
  - Deposits on endplates
- Replacement test cavity under design (SLAC)

Run	Configuration	B [T]	Gradient [MV/m]
1	flat Cu plates	0	19
2		3	9.5
3	Be buttons	0	27
4		3	29
5		0	40
6		3	31
7		1.5	33
8		3	33
9	Cu buttons	0	30
10		3	28
11		0	35
12		3	28
13		1.5	30



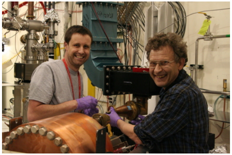
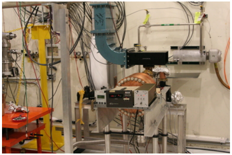
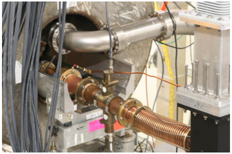
805 MHz program

- Two new vacuum cavities were considered for future use
  - a replacement for the beat-up 805-MHz button cavity (SLAC)
  - a pillbox Be-wall cavity (LBNL)
- preferably with no coupler issues
- Arrived at modular design
  - replaceable end walls
  - coupling and diagnostics on center ring
- Dielectric loaded HPRF (Muons Inc.)



All-Season cavity (Muons Inc., LANL)

- modular pillbox with replaceable end walls

All-Season cavity (Muons Inc., LANL)

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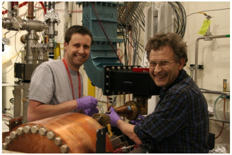

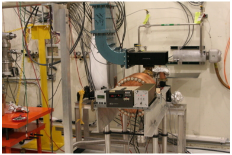

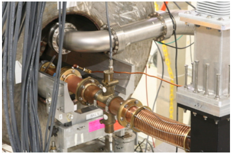

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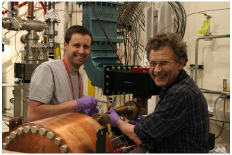

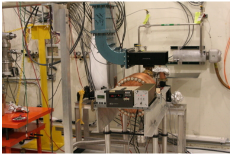

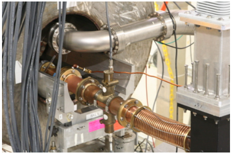

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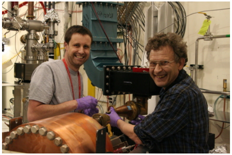

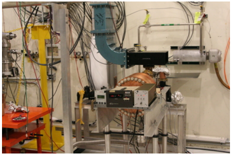

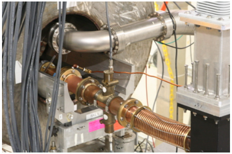

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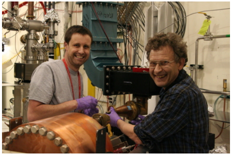

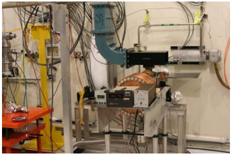

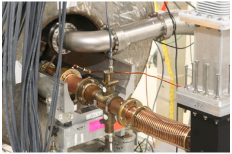

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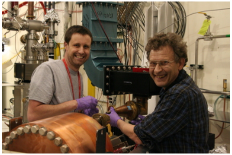

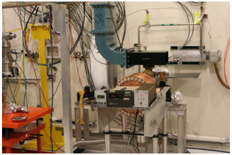

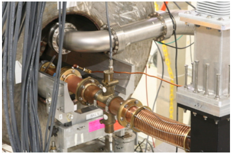

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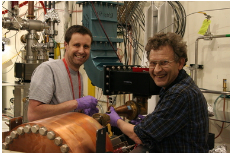

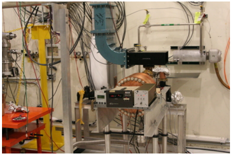

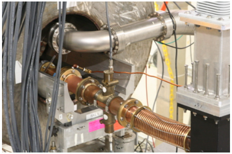

HPRF Program

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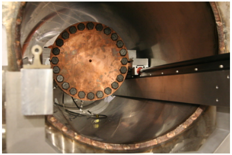
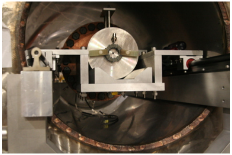
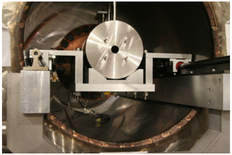

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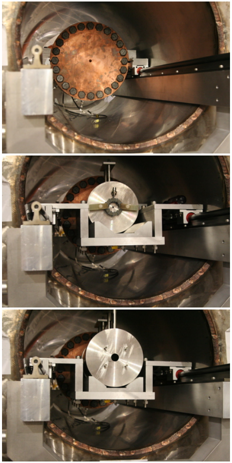

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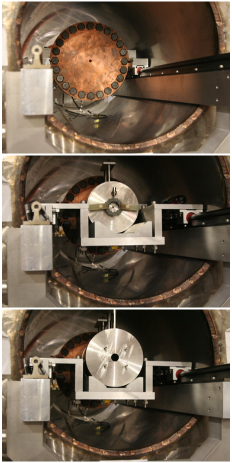

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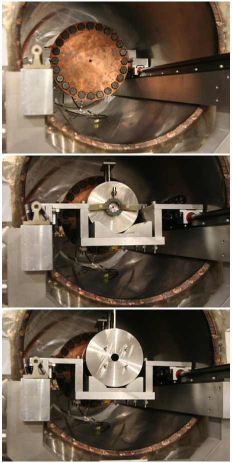

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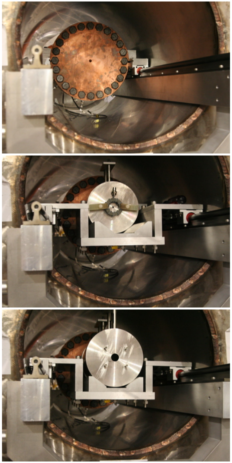

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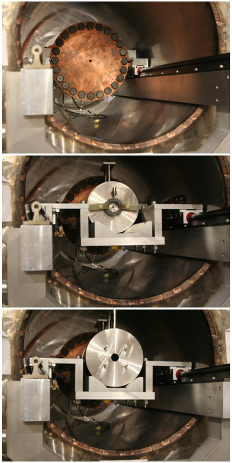

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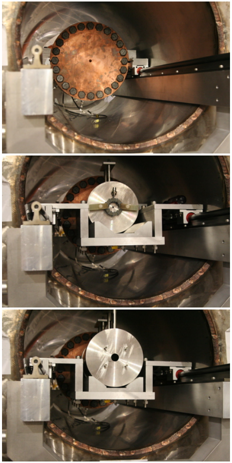
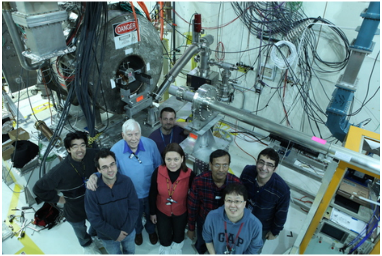
  - Intense muon bunch creates lots of electron-ion pairs
  - potentially shorting the RF cavity
  - mitigated by electronegative dopant gas (K. Yonehara *et al.*, PAC09, IPAC10; Freemire *et al.* IPAC12)

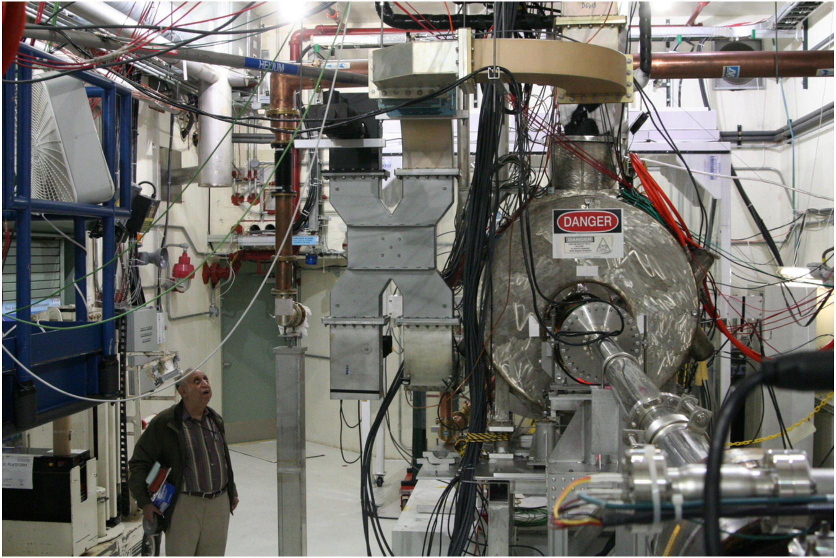


HPRF – 2nd beam test (Spring 2012) – Yonehara

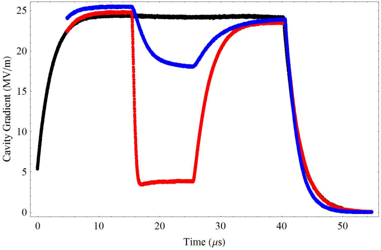
- successfully concluded May 8
  - wealth of physics data starting Apr 18
  - 10^{10}–3×10^{11} ppp
  - 300-1520 psi H2
  - SF6 and dry air dopant at many concentrations
  - also, He+air, N2+air, D2
  - 5-50 MV/m (with high-power hybrid coupler & loads)
  - some data with B=3T
  - Yonehara/Leonova/Jana/Freemire, IPAC12



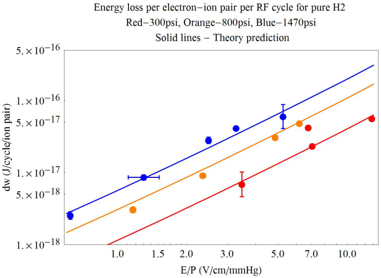
Project X?



Analysis team hard at work (Freemire, Chung, Yonehara, Tollestrup) – good agreement with theory



1470psi H2 (1% dry air)



PRELIMINARY

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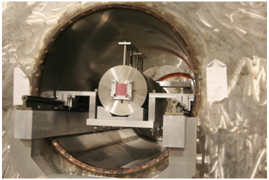

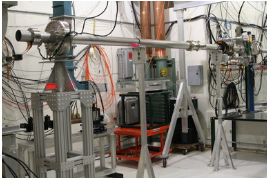

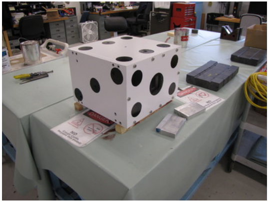

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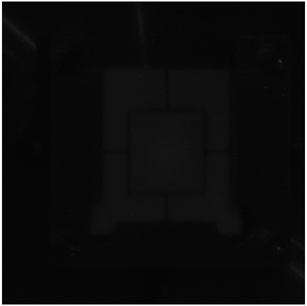

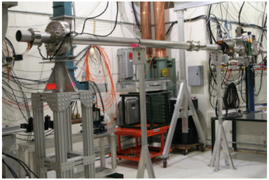

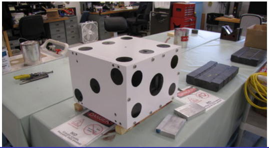

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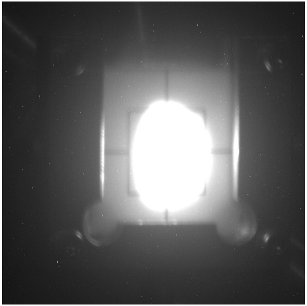

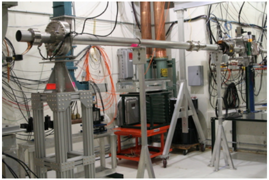

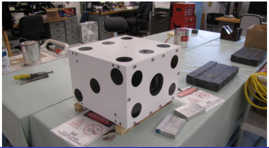

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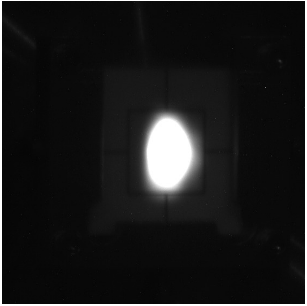

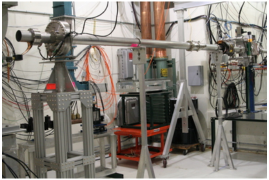

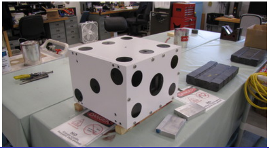

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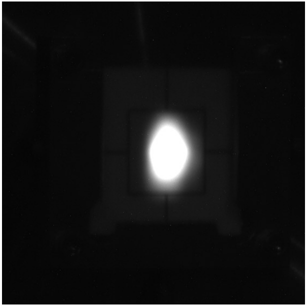

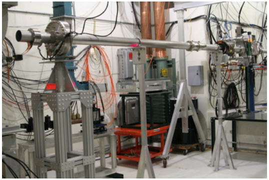

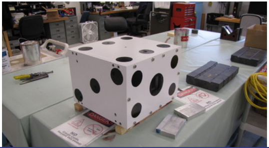

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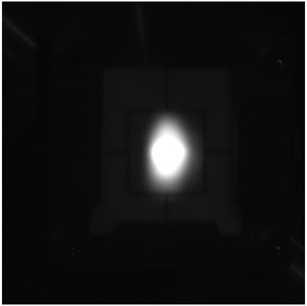

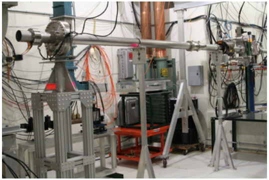

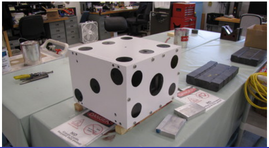

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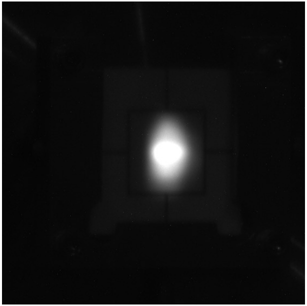

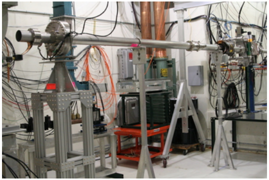

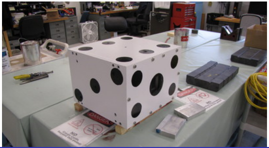

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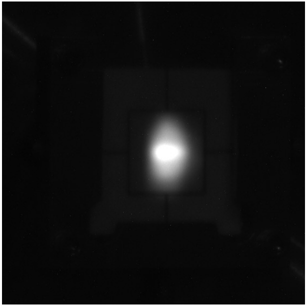

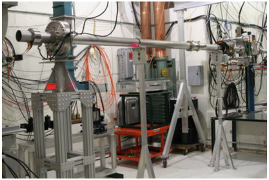

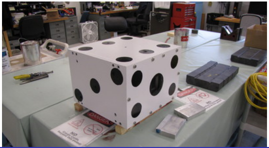

Beamline

- First beam pulse to "emittance absorber" Feb 28, 2011
- Intensity about 1.8×10^{12} protons/pulse at 1 pulse/min
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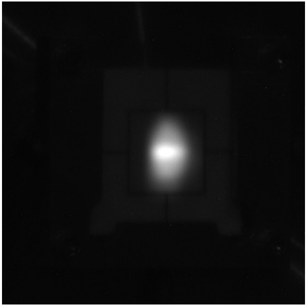

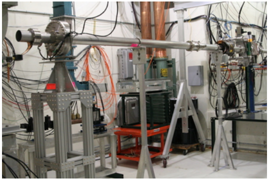

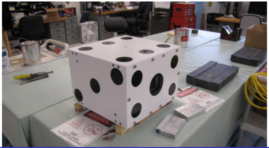

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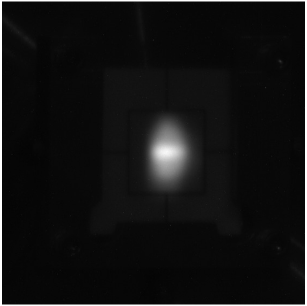

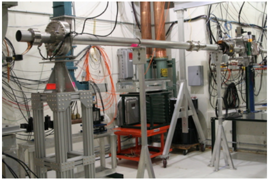

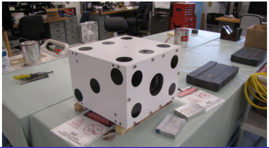

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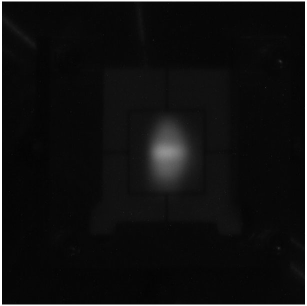

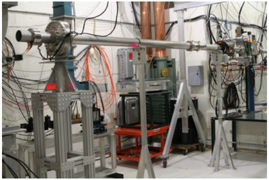

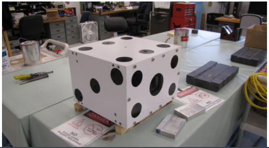

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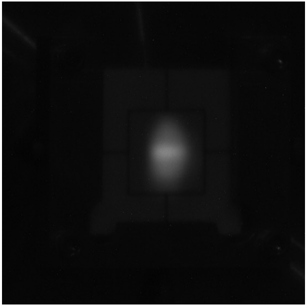

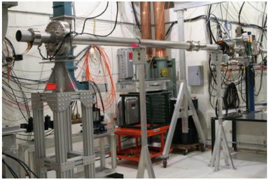

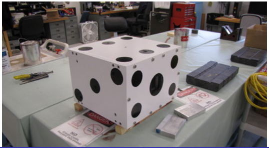

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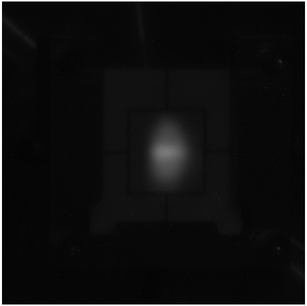

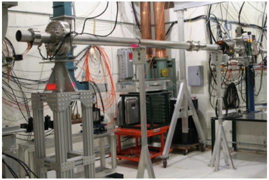

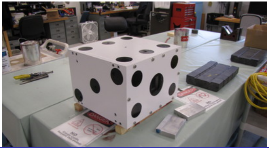

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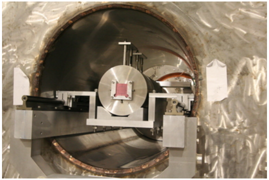
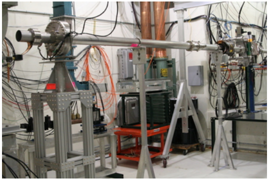
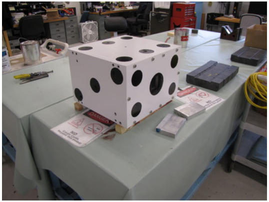
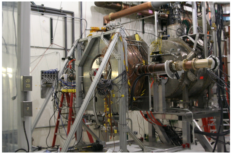






201 pillbox

201 MHz MICE prototype cavity



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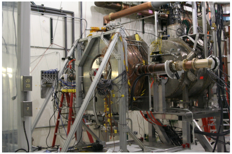
- SRF-like processing (electropolished, etc.)



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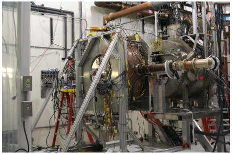

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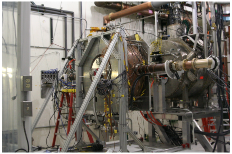

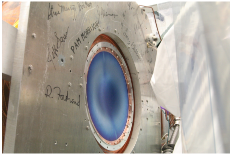

201 pillbox

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- SRF-like processing (electropolished, etc.)
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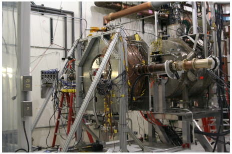
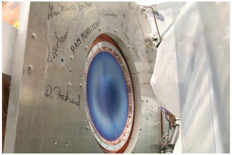
- ran successfully with thin curved Be windows
- operated in stray magnetic field

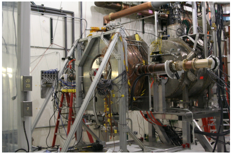


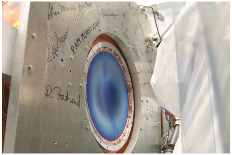


201 pillbox

201 MHz MICE prototype cavity

- SRF-like processing (electropolished, etc.)
- conditioned to design gradient very quickly
- ran successfully with thin curved Be windows
- operated in stray magnetic field
  reduced performance





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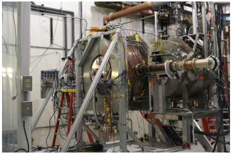

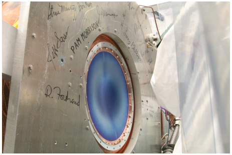

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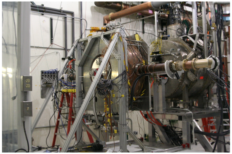
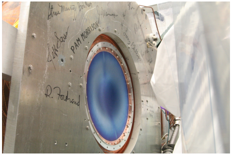
- large diameter coil needed for field configuration closer to MICE





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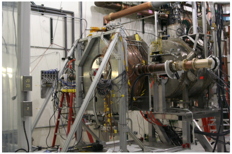
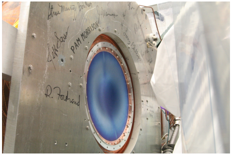
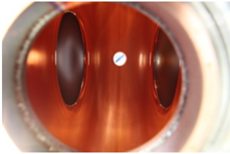
- radiation output measured (MICE detector backgrounds)
- large diameter coil needed for field configuration closer to MICE
- No surface damage seen on cavity interior

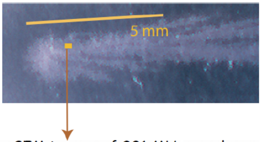




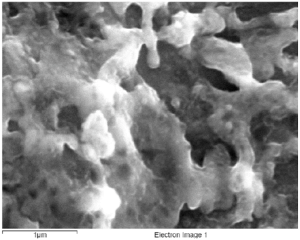


201 pillbox

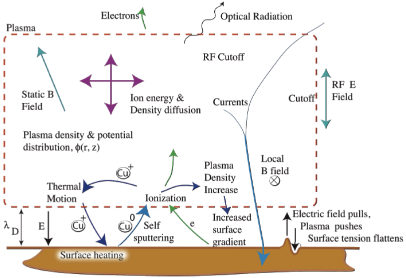
Evidence for some sparking in the coupler



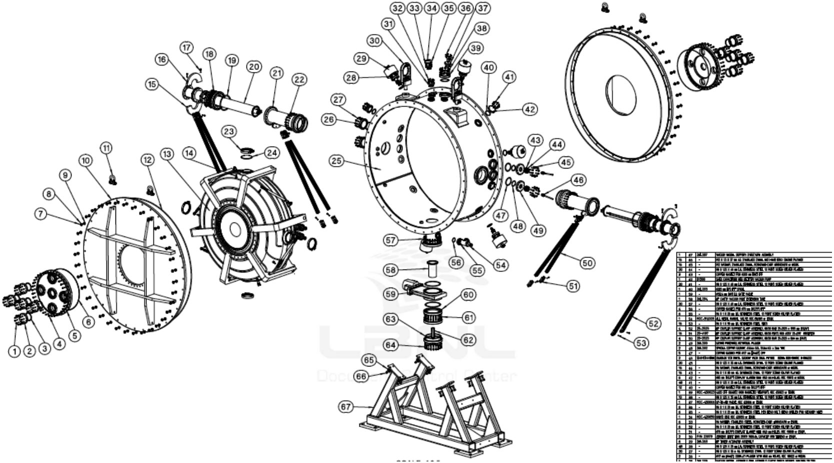
SEM images of 201 MHz coupler.



Unipolar arc? (J. Norem)



201-MHz Single-Cavity Module



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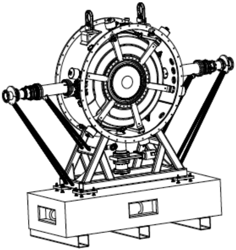
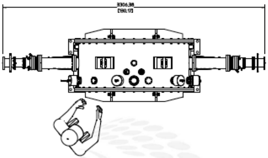
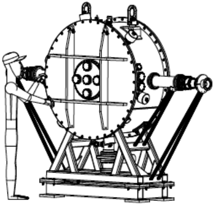


MTA BEAM HEIGHT
CONFIGURATION
Vacuum vessel cover removed





MICE BEAM HEIGHT
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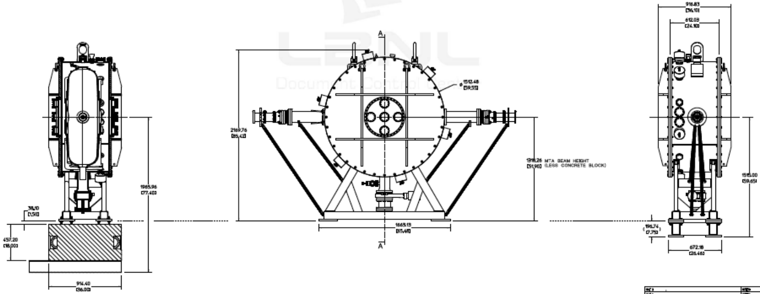


201-MHz Single-Cavity Module

201-MHz Single-Cavity Module Workshop

Tuesday 19 June 2012 from **09:00** to **18:00** (US/Central)
at Fermilab (WH13SE)

Manage

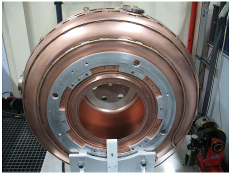
Material drawings pictures

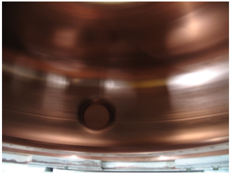
Tuesday 19 June 2012

09:00 - 09:15	Introduction *15'* Speaker: Alan Bross (Fermilab) Material: Slides
09:15 - 09:35	Handling and transport at Fermilab *20'* Speaker: Ryan Schultz (Fermilab)
09:35 - 09:45	Support modifications *10'* Speaker: Ryan Schultz (Fermilab)
09:45 - 10:00	Cavity status *15'* Speaker: Tianhuan Luo (Universtiy of Mississippi) Material: Slides
10:00 - 10:15	Tuners *15'* Speaker: Allan DeMello (Lawrence Berkeley National Laboratory)
10:15 - 10:30	Tuner Control *15'* Speaker: Pierrick Hanlet (Illinois Institute of Technology/FNAL) Material: Slides
10:30 - 10:45	Break
10:45 - 11:00	Couplers *15'* Speaker: Allan DeMello (Lawrence Berkeley National Laboratory)
11:00 - 11:15	RF plumbing *15'* Speaker: Alfred Moretti (Fermilab) Material: Slides
11:15 - 11:30	Diagnostics *15'* Speaker: Yagmur Torun (Illinois Institute of Technology)
11:30 - 12:15	Assembly procedure *45'* Speakers: Allan DeMello (Lawrence Berkeley National Laboratory) , Steve Virostek (Lawrence Berkeley National Lab)
12:15 - 13:30	Lunch
13:30 - 13:45	RF measurements *15'* Speaker: Derun Li (LBNL)
13:45 - 14:00	Alignment and scanning *15'* Speaker: James Volk (Fermilab)
14:00 - 14:10	Vacuum system *10'* Speaker: Alfred Moretti (Fermilab) Material: Slides
14:10 - 14:20	Water hookup *10'*
14:20 - 14:35	Safety issues *15'* Speaker: James Volk (Fermilab)
14:35 - 14:45	Schedule *10'* Speaker: Yagmur Torun (Illinois Institute of Technology)
14:45 - 15:00	Future options *15'* Speaker: Yagmur Torun (Illinois Institute of Technology)
15:00 - 15:15	Break

201-MHz Single Cavity Module

- Components
  - 1st MICE cavity EP'ed at LBNL
  - 11 Be windows ready
  - 6 tuner forks fabricated
  - components for 6 actuators fab; need bellows and assembly
  - RF couplers to be built
- assembly area at Lab 6
- rough plan for handling and transport (R. Schultz, J. Volk)
- assembly fixture design in progress (A. DeMello)
- vertical assembly similar to (but much easier than) MICE RFCC
- schedule will be set by assembly fixture and coupler fabrication





Outlook

- Experimental program
  - HPRF cavity in beam – 2nd test finished
  - HPRF breakdown study (no-beam) – finished
  - All-season cavity (true pillbox) run next
  - 805-MHz pillbox cavity with grid windows (Summer)
  - 201-MHz single cavity module (Fall)
  - New 805 MHz modular pillbox with Be/Cu walls
  - ALD cavity – under design
  - Dielectric-loaded cavity for helical cooling
  - beam tests (HPRF and vacuum) after shutdown
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- Infrastructure
  - beamline upgrade, cryo plant maintenance
  - RF circulator/switch installation/commissioning
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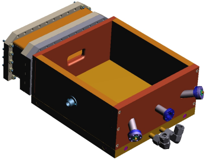
BACKUP

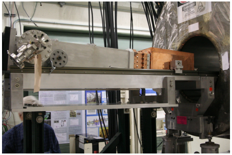
Useful reading

Serious degradation of RF cavity performance in strong external magnetic fields.
Currently main focus of MuCool.

- Magnetic field effect first seen at Fermilab's Lab-G with a 6-cell 805-MHz cavity
  J. Norem *et al.*, Phys. Rev. ST Accel. Beams 6 (2003) 072001
- Studied in more detail at MTA with 805-MHz pillbox cavity
  A. Moretti *et al.*, Phys. Rev. ST Accel. Beams 8 (2005) 072001
- Various models proposed
  A. Hassanein *et al.*, Phys. Rev. ST Accel. Beams 9 (2006) 062001
  R. B. Palmer *et al.*, Phys. Rev. ST Accel. Beams 12 (2009) 031002

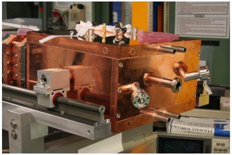
- Rectangular geometry chosen for test cavity to allow fast fabrication and simplify analysis
- Support system designed to rotate cavity pivoting around magnet center by up to 12^o
- Rectangular coupling aperture with rounded edges and a coupling cell built to match the power coupler to waveguide
- Three CF flange tubes for rf pickups and optical diagnostics
- $f_0 = 805.3$ MHz, $Q_0 = 27.9 \times 10^3$, coupling factor 0.97
- YT *et al.*, IPAC10

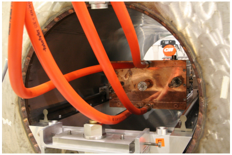




Box Cavity

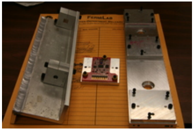
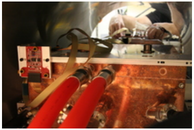
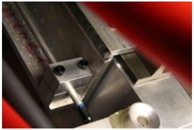
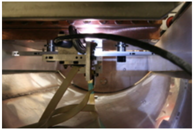
- Operated in the MTA magnet Mar-Sep 2010
- Commissioned to 50 MV/m at B=0
- Took data at 0, ± 1, 3, 4^o wrt B axis (3T)
- Large effect seen at 3-4^o (stable gradient down to about 25 MV/m)
- Some degradation even at $\leq 1^o$ (33 MV/m)
- Visual inspection of interior, no obvious damage
- RF, optical and X-ray signals during sparks saved for analysis
- Magnetic insulation seems to work but not well enough to make up for lost shunt impedance
- Dropped from list



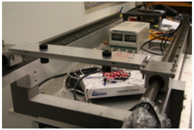


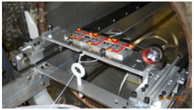
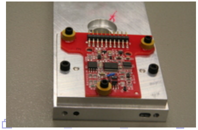
Magnetic Field Mapping

- Magnetic insulation depends strongly on angle
- MTA solenoid field never mapped in detail before
- Expect good alignment of magnetic axis with bore based on manufacturing tolerances but wanted to confirm

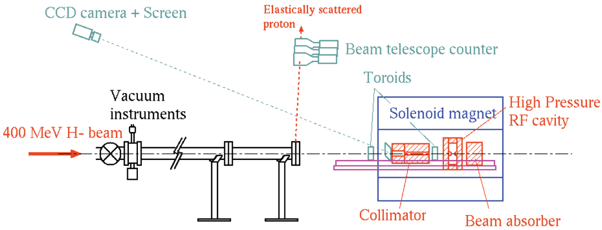





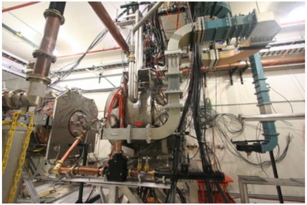
- Fiducial holes drilled during cavity fabrication
- Machined blocks to mount NIKHEF sensors
- Used cavity as mounting fixture – data taken at corners
- Gaussmeter fixed in bore for normalization
- Bore mapped in detail with cart on rails

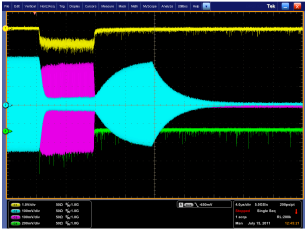


HPRF – 1st Beam Test (Summer 2011)







- 500 psi N2
- 500, 800 and 950 psi H2
- 8μs beam, 2 intensities
- dopants (N2, SF6)

Possible Schedule